Photobioreactors AM Breakout Session

Emerging Ideas Workshops

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March 27, 2012

What approaches offer the greatest opportunity? Light manipulation? Increasing surface area to volume ratio? Improving material lifetime, stability, and reducing degradation?

- High surface area/volume will be difficult to practically design and deploy, and mass transfer challenges
- Light management technologies were considered to have the most potential for disruptive technology applications (delivery, diffusion, optimal use of the spectrum, thermal management)
    - Need to manage light intensity throughout the day, along with nutrients
    - Utilize computational power to model new systems & technologies
    - Light management can also address thermal management

What is the ultimate optical system for collecting, manipulating, and delivering light to a photobioreactor? Within a reactor?

- Target specific wavelength generation and illumination; efficient wavelength shifting (up from IR, down from UV)
- Directing light to optimal locations in the reactor and controlling intensity are big challenges.
- Polymer film properties that can be conditionally changed to adjust reflectivity, light management, to be optimal for photobioreactors (reject IR without losing VIS at mid day).
- Series of backlit slabs (LCDs) could be a uniform and predictable method to deliver light, compared to fibers. Slabs can leverage existing LCD technologies (80 inch TVs).
- Slabs will need to be bio-compatible, and allow transport of media and products; integrity of optical properties is essential
  - Do we need novel materials with the desired optical, chemical, and thermal properties that are compatible with growth conditions? Yes. Optical stability of plastics needs to be addressed.

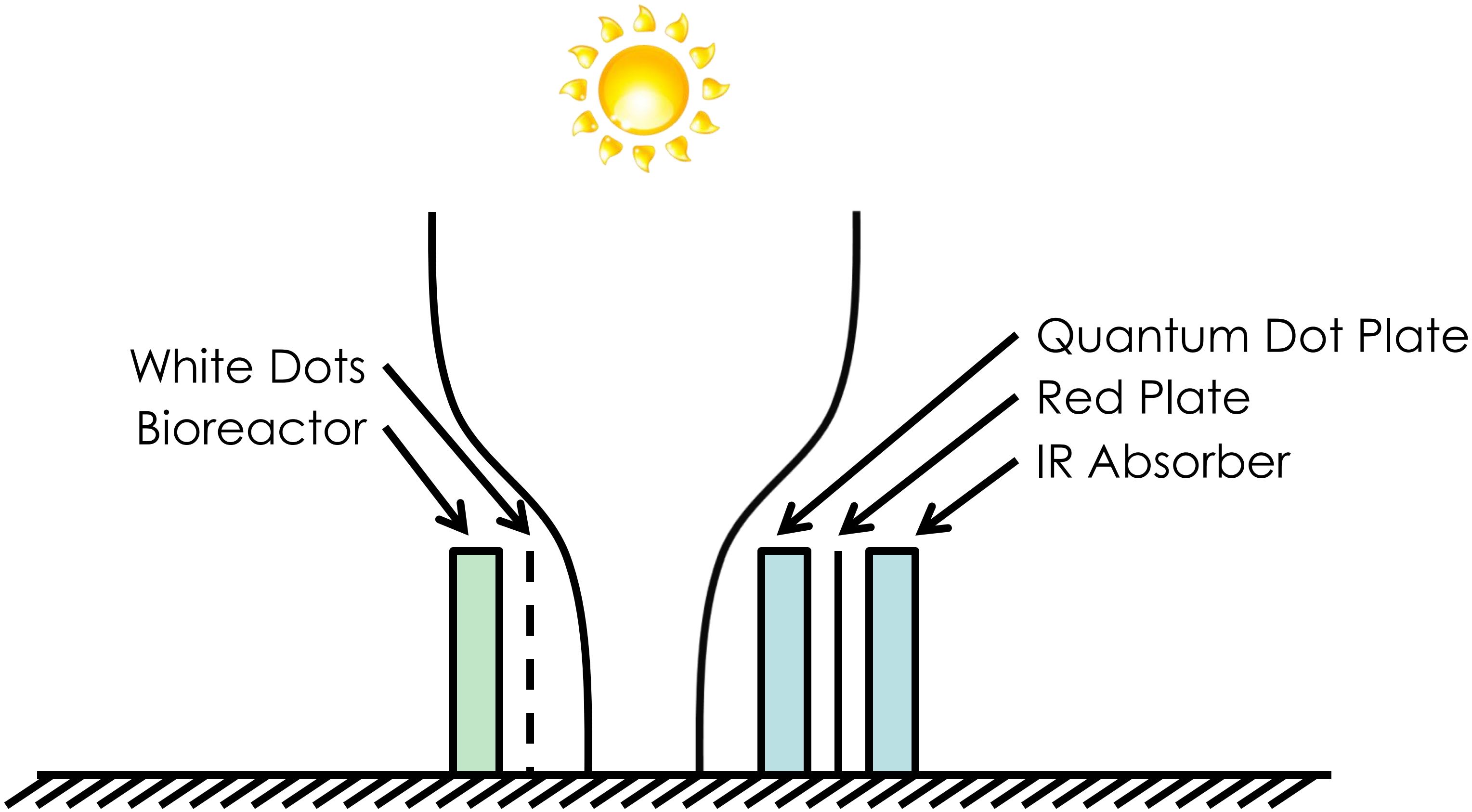
How would bioreactor designs change if this light delivery system was possible?

- Would allow reactors to be deployable in various geographies.
- Can integrate PV/electricity generation with the bioreactor, incorporate thermal control of unused wavelengths (IR), prevent light from escaping from the reactor for optimal use by the organism.
- Mixing the growth media may be a simpler solution for modulating light, but will require mixing and pumping.
- Diffuse light delivery (400 W/m^2 dropped to 40 W/m^2) may overcome physiological requirements for a dark cycle…but one needs technology to effectively capture and use the "rest" of the light (multi-pass light technologies).
- Tapered lighting slabs (LCDs) may be a strategy to optimize light delivery and use.

Can these reactor systems be stably operated for week, months? How can one design to avoid contamination? What are the major contaminants?

- Rapid separation of products
- Solid state reactor control/mitigation of contamination
- Physical and biochemical properties of the system

Draw picture(s) of several promising reactor setups?



- How many useful photons per second hit target, vs. not useful photons not hitting target
- How much additional light can be utilized using quantum dots
- Look at Photosynthetic efficiency as a metric
- Bioreactor shown is perhaps 1 meter tall and 0.1 meters wide

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Where is the ARPA-E white space? Are there new technologies that can put us on new learning curves? Long term, why might this be successful?

- Light management & Integration of technologies for delivery of diffuse light, UV downshifting, IR control, PV
- Key Attributes:
  - Light Delivery: Manipulating concentrated light and then deliver uniform and predictable diffuse light to reactor
  - Light Efficiency: Downshifting UV; shifting IR to shorter wavelengths
  - Light Collection: Must account for weather/diffuse light (hybrid lighting)
  - Heat Management
  - Bioreactor volume/cavity
  - Minimal connections and liquid handling
  - Robust technology life cycle
  - Ground supported
  - Adjustable angling

What are the high level techno-economic metrics necessary for commercial adoption? What fundamental materials and process performance metrics are necessary for success?

- Current technologies for light management:
  - physical methods: mixing, large surface areas to diffuse light

- Performance metrics for light management (for all systems):
  - How much additional light can you "pull" into the system?
  - % increase in PAR photons (improvement in additional spectrum utilization)
  - % photons used for fuel/production
  - volumetric productivity
  - Thermodynamics limits photosynthetic energy conversion to 10-12%, what can be done with the rest of the light
  - IR reflected, absorbed, used, lost as heat
  - Minimum metric biomass accumulation (g/L/hr)

What can be done with $3-4M, 2-3yrs? What is the largest prototype that could be built under this budget? Is there any value to funding seedlings <$1M? What are appropriate targets 1-yr? 3-yrs?

- Complete bioreactor vs. component development…unlikely that a complete bioreactor could be delivered at that level of funding
- Focus on critical path issues, get technology to a point where the market picks it up
- Seedlings could be useful, 2-year "period of performance"
- Phased approach to technology development seems like a reasonable approach
  - Phase I: Design, modeling, TEA, component prototypes (provides necessary flexibility for innovation)
  - Phase II: Bioreactor technology integration (w/ commercial partner)
- Develop computational models to simulate light and the microorganism

What advances/breakthroughs (if any) have there been in the last 10 years that might make this possible now? What are the most promising classes of materials, optical systems, coatings, bioreactor designs?

- Thin films
- Computational modeling
- Fabrication of LCDs
- Nanotechnology (quantum dots)
- Biotechnology (-omics)

- Other expertise:
  - Material science and technology (engineered polymers, textured foils, biocompatible materials)
- Other applications:
  - Photocatalysis
  - Photovoltaic